Summary on
HeartQuake: Accurate Low-cost Non-Invasive ECG Monitoring Using Bed-Mounted Geophones

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Objective

The present environmental conditions and people's lifestyle has engraved significantly large fraction of the population to suffer from heart diseases that are leading to major life issues or even death resulted from lack of prior prediction or untimely happening of the illness. So, the only solution is to get continuous data of the heart abnormalities whether day or night including while sleeping, because many people encounter heart attacks during their sleep. There are currently numerous existing approaches like smartwatches, wearable devices, and technologies like RF signals, smartphone accelerator, multi-sensor platform, etc., to check heart rate, but detecting only heart rate is insufficient to discover many other common heart ailments. There also exists few sensing technologies such as electric, seismic, acoustic, and optical, out which electrocardiography (ECG) is most used and efficient for detecting heart characteristics but all of them are costly to deploy widely. Therefore, the main objective of this paper is to acquire five core ECG peaks (P, Q, R, S, T-peaks) using a geophone-based sensing system, which is non-intrusive, low-cost, and accurate for diagnosing various heart conditions.

Introduction

This research paper on "HeartQuake" is an innovative approach to obtain the ECG pattern for detecting heart conditions for anyone at the hospital or at home at any time of the day. The present ECG machine is efficient, but its high cost ($10000 to $30000) makes it too hard to widely deploy. Also, the ECG sensors require a tight band around the chest or electrodes to be stuck at specific places on the body, which is difficult to be used constantly. Unlike any other devices such as Holter monitors, Qardio QardioCore, Zephyr Bioharness, smart devices, etc., that are cumbersome, expensive, and could only extract abstract forms of cardiac activity, "HeartQuake" recognizes cardiac activity through vibration patterns captured by geophone attached to the occupant's bed. These vibration patterns are then filtered for noise cancellation and passed to the bidirectional long short term memory (Bi-LSTM) deep learning model for estimating the ECG waveform (five core peaks). This method with minimal hardware components is inexpensive (~ $100), unintrusive with the body, gives an average timestamp estimation accuracy of 13.36ms with general model and 9.37ms with a personalized model for all five ECG peaks.

Working

The "HeartQuake" system is mainly focused on its accessibility to all the patients who want to inspect their heart activities all the time, even at home after getting discharged from the hospital. The hardware component involved in this system is a SM-24 geophone sensor attached to the bed's mattress of the subject (patient), which consists of a coil, magnet, and two springs to measure the vibrations using inertial mass suspended from them. This sensor provides seismic sensing with a sensitivity of 28.8V/m/s and produces a 10kHz raw analog signal that gets amplified with a gain of 90dB and digitalized by a Raspberry Pi3 to obtain even minute measurements of the sleeping user's vibration patterns (heartbeat, respiration). The authors have also considered the noise induced by the sensor that interferes with the user's data. To identify the amount of noise indulged, Fast Fourier Transform is performed on the signal and confirmed that 5-30Hz is the core frequency band that needs to be extracted from raw vibration signals. To remove this sensor noise and noise by respiration pattern, the raw signal is passed through a bandpass filter. Then, a deep learning (neural network) model is constructed using i) self-collected baseline dataset (filtered vibration data with ground truth ECG signals) from 21 subjects for 10 min, ii) CEBS data (SCG and related ECG data) from 20 subjects for 60 min duration. Later, an input of 750 data points of vibration data is fed into a designed deep learning model and concatenated with 3s of data to ensure full heart-beat cycles, then passed through a two-stacked Bi-LSTM layer with hyperbolic tangent activation function which is again passed into the third layer called Regression layer to obtain the ECG estimated output (T=750). The results are then compared with an FDA-approved Zephyr Bioharness sensor ECG signals and obtained accuracy as follows: R-peak with 6.66ms error, RR interval with <3ms error, and QRS complex width having error <10ms. The system was also examined in longitudinal study with 15 additional volunteers apart from 21 volunteers in the baseline data collection. The results showed that low average peak estimation errors of 15.83ms, 8.50ms for general and personalized models respectively.

Evaluation

Almost all the experiments of this paper are conducted on a foldable bed with a couch-type mattress and the QRS detection algorithm by Tompkins is used for evaluating HeartQuake under different practical scenarios. The various scenarios considered for evaluation are i) Evaluation with baseline dataset, ii) Impact of motion and posture, iii) Impact of external vibrations, iv) Impact of sensor location, v) Performance on different mattresses, vi) General vs personalized model, vii) Amplitude. To summarize, five subjects were asked to sleep on mattress in different postures, there has been an error of ~28ms in some postures, with external vibrations into account, the peak estimation error increased to 18-21ms. For sensor location determination, the sensor has been placed in 5 different places and when the sensor is not close to the origin of the heart, mean peak detection error was observed between 18-23ms. The performance of the HeartQuake system was limited to only three types of different mattresses, couch-type (13.26ms error), spring-type (18.34ms error), and latex-type (21.61ms error). All these mentioned results are for a general model but for personalized model, it has been observed that error in peaks has decreased to a noticeably lower amount. Also, with output range [-1:1], the absolute peak amplitude estimation error is 0.11 for general and 0.07 for personalized models.

Results

Lastly, a total of 10 ECG patterns i.e., a pair of body-attached sensor collected from CEBS dataset and HeartQuake-generated ECG data from self-collected baseline dataset are randomly provided to 11 clinical doctors (cardiologists, physicians, traumatologists) and asked to evaluate and distinguish their sources. The responses explained that data from CEBS dataset and self-collected baseline dataset were hardly distinguishable, and their accuracy were matched perfectly up-to 97.4%.

Conclusion

The “HeartQuake” system is efficient in getting the ECG waveform for detecting different heart ailments like arrhythmia, myocardial infarction, valve failures etc., in a simple setup, but it still has few limitations to overcome. Though it considered all the factors that can impact the performance like internal noise, external vibrations, different surfaces, sleeping postures etc., they could not get a chance to test on real patients directly but managed to obtain CEBS data from patients of ectopia heart beats for Arrhythmia detection Case-study. The RR interval, QRS complex width, ST segment length, QT interval, PR segment length and PR interval are all analyzed, tabulated, and graphed in time-series function for evaluation of accurate ECG waveform estimation. Thus providing effortless, painless way for heart activity recognition.

Future Scope

Considering all the advantages, disadvantages and working of the “HeartQuake” system, one can conclude that there is large scope for improvement in the system. For the future scope, the system can be tested on real patients with different kinds of heart abnormalities in diverse practical applications. Also, techniques like amplitude modulation, spatial information extraction can be applied to separate multiple signals for capturing ECG for more than one bed occupant.